U.S. Army Corps of Engineers, Detroit District Lake Michigan Potential Damages Study

Task 3.3.2

Assess Costs of Higher and Lower Design Crest Elevations on Future Shore Protection

FINAL REPORT

July 2000

Prepared by NTH/Wade-Trim Joint Venture

Introduction

This report was prepared as part of the Lake Michigan Potential Damages Study (LMPDS) – Phase III for the US Army Corps of Engineers, (USACE) Detroit District. Under Task 3.3 – Estimate Future Costs for Structural Protection, the influence of changes in water levels as a result of alternate hydrologic scenarios or modifications to the regulation procedures must be assessed in terms of alternate or avoided costs of structural protection. Baird and Associates developed preliminary estimates of costs for shore protection over a 50-year period as part of the 1993 International Joint Commission (IJC) Levels Reference Study. This work needs to be conducted in conjunction with work undertaken under Task 6.7, which focuses on the effects of changes in the lake levels on the stability of typical shoreline structures.

The objective of Task 3.3.2 is to assess the costs of requiring higher and lower design crest elevations for shore protection structures on a per meter cost basis. More specifically, design crest elevations will be varied above and below a baseline structure height to assess the impacts on cost. To be consistent with the Task 6.7 work, the costs for shore protection structures estimated in this report are developed for the typical shore protection structures identified in Task 6.7. The shore protection structures evaluated within this report are based on designs developed using standard coastal engineering procedures. The results from this report are specific to Lake Michigan, but the methodology used may be used to assess cost impacts associated with changes in crest height on other shorelines.

Shore Protection Types

There are various shore protection structures along the Lake Michigan shoreline. The selection of shoreline protection structures depends on such factors as location (marina, harbor, or private property), soil conditions, environmental impacts and economics. Three specific types of shore protection structures along with the typical configurations and design parameters for each were identified in the Report on Shore Protection Structures for Task 6.7 by the NTH/WTA Joint Venture dated April 2000 of the Lake Michigan Potential Damages Study. The structures identified in the report include seawalls/bulkheads, revetments, and groins.

The report herein describes and summarizes the results for the assessment of cost impacts due to an increase or decrease in design crest elevations for three typical structures identified in Task 6.7. Specifically, the following structures were identified and will be evaluated to assess potential cost impacts for higher and lower design crest elevations in this report:

- 1. Seawall/bulkhead Steel Sheetpiling
- 2. Revetment Riprap Revetment
- Groins Concrete grout-filled geotextile groins

For more detailed information concerning the selection of the structures above, please refer to the Task 6.7 Report, Shore Protection Structures, Lake Michigan Potential Damages Study.

Design Considerations

To assist in the evaluation, design criteria for each shore protection type along with general assumptions and typical design considerations were established. Depending on the local, state, and federal regulations, different requirements may exist for implementing shore protection. A shore protection structure may be designed and installed to varying standards – such as by a professional engineer, marine contractor, or individual property owner. For this evaluation, it is assumed that shore protection structures will be designed by a professional engineer and installed by a qualified marine contractor. Therefore, the design guidelines set by the Corps of Engineers as indicated in engineering manuals such as the Shore Protection Manual (SPM), Design of Coastal Revetments, Seawalls, and Bulkheads (EM 1110-2-1617), and Coastal Groins and Nearshore Breakwaters (EM 1110-2-1614) will be utilized in this evaluation.

Seawall/Bulkhead – Steel Sheetpiling

The key components for a well-engineered steel sheetpile wall include:

- Anchored Sheetpile Wall (including wales, rods, and anchors)
- Toe Protection
- Splash Apron
- Drainage system on landside

Anchored rather than cantilevered sheetpiling is used in this analysis because of the potential lateral deflections due to wave action at the site. The general design of a sheet pile wall requires a structural analysis of the structure to determine bending moments and shear forces caused by the earth and water pressures. This analysis will identify the required depth of the piling, the anchor force and maximum bending moment and consequently the required material and cross-section or shape of the sheetpiling. The United States Steel (USS) Steel Sheet Piling Manual was used to assist in the design of the sheetpiling. A spreadsheet was developed to evaluate the sheetpiling design.

The results from the structural analysis are most dependent on the structure height or crest elevation and the soil properties at the structure. The higher the design crest required, the greater depth of penetration required. Likewise, lower design crest elevations will dictate lower depths of penetration. The soil properties used in this analysis are based on the design parameters identified in Task 6.7 as typical for Lake Michigan structures.

Design water levels and wave characteristics dictate the height of the structure required. The wave height at the structure will also dictate the toe protection required at the base of the sheet piling and will indicate whether overtopping of the structure will occur. Toe protection is required to protect the bottom of the sheetpiling from being undermined from wave action at the structure. When overtopping does occur, the soil on the landside of the structure may erode. Therefore, when overtopping of the sheetpiling is expected, a splash apron is commonly placed behind the sheetpiling to prevent erosion of the landside of the structure.

The design parameters and assumptions used in this evaluation include those indicated in the Task 6.7 report, the report by Baird & Associates for the Illinois Shoreline Lakebed

Paving Plan Feasibility Study, and the USACE Engineering Manuals identified previously. The following is a list of the design parameters and assumptions used in the steel sheetpiling analysis along with their corresponding reference:

- Design Wave at Structure = Breaking Wave (Hb) at design water level, (Future Avoided Costs of Shore Protection, IJC Levels Reference Study, W.F. Baird & Associates Coastal Engineers, Ltd.)
- Design Crest Elevation = Design Water Level at Structure (ds) + 1.0 Hb, (Future Avoided Costs of Shore Protection)
- Depth of Penetration (D) = 2 x Design Crest Height, (Task 6.7)
- Slope of lake bed: 1:10, (Task 6.7)
- Height of typical sheetpile structure = 5 ft, (Task 6.7)
- Assume drainage features on interior of shore protection are adequate to handle runup/overtopping

The figure below from the USACE Engineering Manual for the Design of Sheet Pile Walls (EM 1110-2-2504) illustrates the design evaluated for the anchored steel sheetpile although toe protection was added to the sheetpiling for this evaluation.

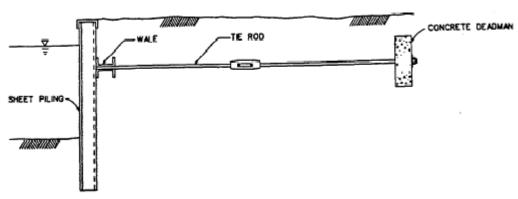


Figure 1. Steel Sheetpiling Design (Figure 2-2, EM 1110-2-2504, 1994).

A sample calculation for the anchored steel sheetpile design is included in **Appendix A**.

2. Revetment - Riprap Revetment

The major components of a revetment include:

- Armor or Cover Layer
- Underlayer/Filter
- Toe Protection
- Splash Apron
- Drainage system on landside

The general design of a revetment requires the calculation of required armor unit sizes to sufficiently protect the shoreline from wave action. For this evaluation, the design wave at the structure is assumed to be a breaking wave, which is equal to 78% of the design water depth. The design crest elevation is assumed to be equal to the design water level plus the breaking wave height. A suitable armor unit is selected based on the design wave height and the slope of the structure. The larger the wave height is at

the site, the larger the stone size will be required. Therefore, higher design crest elevations will generally require larger stones, while lower design crest elevations, will require smaller stones. The underlayer/filter support the cover layer, permits the seepage of water and prevents the scouring of existing soil beneath the structure. Toe protection will protect the bottom of the revetment from being undermined and prevent the displacement of the stone within the revetment. The figure below from the USACE Engineering Manual for the Design of Coastal Revetments, Seawalls, and Bulkheads (EM 1110-2-2504) illustrates the design evaluated for the riprap revetment shore protection structure.

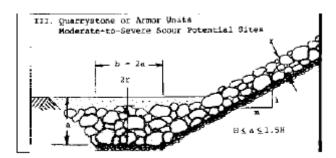


Figure 2. Revetment Design with Toe Protection (Figure 2-4,EM1110-2-1614, 1994).

The following is a list of the design parameters and assumptions used in the analysis of the riprap revetment along with their corresponding reference:

- Design Wave at Structure = Breaking Wave (Hb) at design water level, (Future Avoided Costs of Shore Protection)
- Design Crest Elevation = Design Water Level at Structure (ds) + 1.0 Hb, (Future Avoided Costs of Shore Protection)
- Slope of revetment 1:2, Conversions with USACE, (Grand Haven)
- Coverlayer (W), (USACE EM 1110-2-1614 and SPM)
- Underlayer (W/10), (USACE EM 1110-2-1614 and SPM)
- Height of typical sheetpile structure = 5 ft, (Task 6.7)
- Assume drainage features on interior of shore protection are adequate to handle runup/overtopping

A spreadsheet was developed to determine the armor size and layer thickness required based on the crest height required and the slope of the revetment input.

The revetment design is based on the USACE SPM, and results in an idealized crosssection for a revetment. In practice, the idealized cross-section would be revised to a recommended cross-section based on stone actually available and practical construction considerations.

Here, the cost of protection is based on the idealized cross-section. However, based upon consideration of the practicality of the resulting layer thicknesses, the cover layer and underlayer would be combined in practice. Accordingly, the same unit price is used for both layers.

A sample calculation for the design of the revetment is included in **Appendix B**.

 Groins - Concrete Grout-Filled Geotextile Groin Design and Steel Sheetpile (SSP) Design

The main function of a groin or groin field is to interrupt the longshore transport of littoral drift by trapping littoral material with a structure perpendicular to the shore. This will help replenish the shoreline with sediment and maintain a stable beach. The placement of groins dictates the location and the amount of sand that will be trapped within the groins. The report for Task 6.7 indicates that the concrete grout-filled geotextile groins are the most common type of groin in the Lake Michigan study area, although recent conversations with the USACE indicate that SSP groins are very common for Lake Michigan. Therefore, both the grout-filled geotextile tube and SSP groins are considered in this section.

Based on USACE Manuals (EM 1110-2-1617 and SPM) and conversations with USACE staff and W.F. Baird & Associates, Ltd., it was determined that the typical design for groins require that the top of the groin be placed so that they are even with the design water level. The grout-filled tubes are generally placed directly on the shore bed without excavation and/or toe protection. The tubes are stacked in a pyramid formation with two tubes on the bottom and one tube on top. The SSP groins are constructed similar to that described in the previous section on steel sheetpile design for shore protection, because the design is based on soil, water, and wave forces. Although the crest of the SSP groin will be level with the design water level. The SSP groins are typically implemented with toe protection to prevent undermining of the structure.

Conversations with the USACE, Detroit District indicated that the groin structures are generally tied to the bluff of the shoreline and that the USACE has limits or regulations, which dictate the height and length of the groins. Typically, the groins are constructed up to these limits to maximize the benefits of the groins. These limits are based on historical data and are in place to ensure that shorelines near the location of the groins are not impacted. The basic function of the groin is to trap litter and material that is being transported along the shoreline. By trapping material transported, the shoreline downstream of the groin will tend to have increased erosion due to the decrease in material being deposited. Whether there is a decrease or increase in the water level, the groins will be tied to the bluff and the height and length of the groins will conform to the limits set by the USACE. Due to these findings, it was determined that the per meter cost to implement shore protection using groins would not change due to lower or higher water elevations.

Water Level Impacts on Design Criteria

The overall impact of changing water levels on design criteria should be considered with regards to maximum design water levels. The maximum design water level dictates the height of the structure. It is needed to estimate the maximum wave height at the structure, the amount of runup to be expected, and ultimately the required design crest elevation of the structure. Design still water lake elevations are typically obtained from historical observations of gauging records nearest to the project site.

 Under scenarios of increasing water levels, it is assumed that design water levels typically used, such as the 20-year return period still water elevation, would be increased in response to higher recorded lake levels.

- Under design scenarios of decreasing water levels, it is reasonable to assume that 20-year design water level elevations would be reduced.
- Low water levels may increase the scour potential at the site due to wave action occurring at the base of the structure. This may require widening toe protection lakeward to prevent undermining of the structure.

Costs

The first step in assessing the relative changes in cost due to changes in design water levels was to develop a basic or reference design using existing design standards for the typical shore protection structures. Structures for residential shore protection based on typical conditions for Lake Michigan were selected as the "existing" structures. Once the existing structure design and cost procedure were established, changes in design crest elevations were made and the resulting costs for implementation tabulated. Since the focus of this evaluation was on the relative changes to implement new shore protection, modifications or repairs of existing shore protection are not evaluated.

The basic costs of shore protection include design costs, permit fees, materials, mobilization and demobilization of construction equipment, construction labor, and operation and maintenance. It is assumed that operation and maintenance costs will not vary significantly with relatively small changes in structure elevations. Therefore, operation and maintenance costs are not considered. The costs of the remaining elements are assumed to remain constant regardless of lake level except for construction labor and materials.

The construction labor and material elements that are most likely to change due to the change in lake level are included in the evaluation of the structures' cost. The remaining elements, including site preparation costs for site clearing, excavation (except in terms of toe protection), grading, splash aprons and drainage systems on landside were assumed to be equal for each structure and were not included in the total cost of each structure.

The construction elements of a typical seawall/bulkhead and revetment are listed below:

Seawalls/Bulkheads - Anchored Sheetpiling

- Sheetpiling
- Wales, rods, and anchors
- Toe Excavation
- Toe Protection
- Backfill

Revetment – Riprap revetment

- Cover Layer
 - Riprap
- Underlayer
 - Riprap or gravel
- Toe Excavation
- Toe Protection
- Filter

- Pea Gravel
- Filter Cloth

Cost estimates for the various construction elements were obtained from the Means 1999 – Site and Landscaping Cost Book as well as from conversations with local quarries in Michigan. Cost estimates are presented as base national averages, but can be converted to costs at various locations around Lake Michigan. A detailed cost breakdown for the steel sheetpiling and riprap revetment is included in Appendix C and D, respectively.

Results

Various shore protection structures and methods have been implemented along the Lake Michigan shoreline. Characteristics such as beach slope, soil conditions, water depth, and wave height, which dictate the design of a shore protection structure, vary from site to site. A general, as opposed to a site-specific approach was taken to assess potential cost changes. A site-specific study would require an enormous effort in data collection, calculation and compilation. Thus, our evaluation was based on two typical Lake Michigan shore protection structures. Utilizing the typical shore protection structures implemented along the Lake Michigan shoreline, the typical cost increase or decrease corresponding with a change in crest height could be determined.

The results of this evaluation provide the costs and percent increases or decreases in cost for the implementation of typical shore protection structures on Lake Michigan. Table 1 presents a summary of the cost per meter for the riprap revetment and steel sheetpiling for 1 ft, 2 ft, and 3 ft above and below an "existing" design crest elevation of 5 ft. A design crest elevation of 5 ft is utilized because this height was identified as the typical height of shore protection structures in the study area. It should be noted that results from this evaluation should not be used for design or evaluation purposes for a specific site. In designing a specific structure for a site, it is recommended that site-specific information be obtained.

Results in Table 1 are supported by more detailed costs for the implementation of steel sheetpiling and riprap revetment found in Tables 2 and 3 respectively. These are further supported by detailed cost breakdowns for the steel sheetpiling and riprap revetment located in Appendices C and D.

The cost estimates for the revetment and sheetpiling structures were compared with results from other studies. These include the Illinois Shoreline Lakebed Paving Plan Feasibility Study, bid tabs from recent shore protection projects, and historical cost estimates from the 1993 Final Report for the International Joint Commission Levels Reference Study for Future Avoided Costs of Shore Protection. Table 4 summarizes these costs.

Table 1: Summary of Costs and Percent Change in Cost per lineal meter of structure

				Desig	gn Crest Hei	ght		
Structure		Existing + 3.0 ft	Existing + 2.0 ft	Existing + 1.0 ft	Existing	Existing - 1.0 ft	Existing - 2.0 ft	Existing - 3.0 ft
oli detale		8 ft (2.4 m)	7 ft (2.1 m)	6 ft (1.8 m)	5 ft (1.5 m)	4 ft (1.2 m)	3 ft (0.9 m)	2 ft (0.6 m)
Seawall/Bulkhead:	Cost	\$2,728	\$2,187	\$1,910	\$1,644	\$1,392	\$1,174	\$971
Steel Sheetpiling	Cost increase or decrease to existing	\$1,084	\$544	\$267	Existing	-\$251	-\$469	-\$673
	Percent increase or decrease	66%	33%	16%	0%	-15%	-29%	-41%
Revetment:	Cost	\$1,767	\$892	\$668	\$456	\$276	\$168	\$86
Riprap Revetment	Cost increase or decrease to existing	\$1,310	\$436	\$212	Existing	-\$180	-\$289	-\$371
	Percent increase or decrease	287%	96%	46%	0%	-40%	-63%	-81%
Groins	Cost	-	-	-	N/A	-	-	-
Concrete grout-filled geotextile	Cost increase or decrease to existing	\$0	\$0	\$0	Existing	\$0	\$0	\$0
	Percent increase or decrease	0%	0%	0%	0%	0%	0%	0%

Note: The costs above do not include costs for elements of the structure that do not change in cost due to a change in crest elevation, such as site clearing, excavation (except in terms of toe protection), grading, splash aprons and drainage systems on landside.

Table 2: Steel Sheetpiling Detailed Costs

	Sheetpiling		Backfill			Toe Protect	tion		T. (110)
Design Crest Height	including wales, rods and anchor	Volume	Unit Cost	Cost	Excavation	Pea Stone	Filter Cloth	Cover Layer	Total Cost
	\$/meter	cu yd./m	\$ per cuyd/m	\$/meter	\$/meter	\$/meter	\$/meter	\$/meter	\$/meter
Existing + 3.0 ft	\$1,812	7.8	\$4.30	\$33	\$184	\$98	\$12	\$588	\$2,728
Existing + 2.0 ft	\$1,662	6.0	\$4.30	\$26	\$143	\$86	\$11	\$261	\$2,187
Existing + 1.0 ft	\$1,511	4.4	\$4.30	\$19	\$107	\$73	\$9	\$191	\$1,910
Existing	\$1,361	3.0	\$4.30	\$13	\$77	\$61	\$8	\$124	\$1,644
Existing - 1.0 ft	\$1,210	1.9	\$4.30	\$8	\$51	\$49	\$6	\$68	\$1,392
Existing - 2.0 ft	\$1,059	1.1	\$4.30	\$5	\$31	\$37	\$5	\$38	\$1,174
Existing - 3.0 ft	\$909	0.5	\$4.30	\$2	\$15	\$24	\$3	\$17	\$971

Table 3: Riprap Revetment Detailed Costs

Design Crest Height	Cover Layer	Underlayer	Pea Gravel	Filter Cloth	Toe Excavation	Toe Protection	Total Cost	
Design Great Height	\$/meter	\$/meter	\$/meter	\$/meter	\$/meter	\$/meter	\$/meter	
Existing + 3.0 ft	\$500	\$383	\$88	\$23	\$184	\$588	\$1,767	
Existing + 2.0 ft	\$222	\$170	\$77	\$20	\$143	\$261	\$892	
Existing + 1.0 ft	\$162	\$125	\$66	\$17	\$107	\$191	\$668	
Existing	\$106	\$81	\$55	\$14	\$77	\$124	\$456	
Existing - 1.0 ft	\$58	\$44	\$44	\$11	\$51	\$68	\$276	
Existing - 2.0 ft	\$32	\$25	\$33	\$9	\$31	\$38	\$168	
Existing - 3.0 ft	\$14	\$11	\$22	\$6	\$15	\$17	\$86	

Table 4 - Other Shore Protection Cost Data

Average Shore Protection Costs for Typical Great Lakes Structures (1992) Average Cost Per meter converted to 2000 dollars

		Stone	Steel Sheet Pile	,	Steel Sheet Pile
Source	Re	evetments	Seawalls		Groins
CA, Inc	\$	196	\$ 748	\$	394
Ontario Ministry of					
Natural Resources	\$	1,086	\$ 1,154	\$	2,380
SEWPRC	\$	1,998	\$ 2,885	\$	2,886
W.F. Baird, Inc.	\$	991	\$ 1,940	\$	1,388

Source:

Future Avoided Costs of Shore Protection, Final Report, International Joint Commission Levels Reference Study, Working Committee 2, Potential Damages Task Group, W.F. Baird and Associates Coastal Engineers Ltd. Ottawa, Ontario, March 1993

Design Crest	Stone	Steel Sheet Pile	Steel Sheet Pile
Elevation (ft)	Revetments	Seawalls	Groins
7.2	\$ 1,900	\$ 4,100	\$ 2,000
8.9	\$ 2,700	\$ 4,850	\$ 2,000
10.5	\$ 3,600	\$ 5,700	na
12.1	\$ 4,700	\$ 6,600	na
13.8	\$ 5,900	\$ 7,550	na
15.4	\$ 7,300	\$ 8,000	na

Source:

Final Report - Illinois Shoreline, Interim IV, Lakebed Paving Plan Feasibility Study, Baird and Associates.

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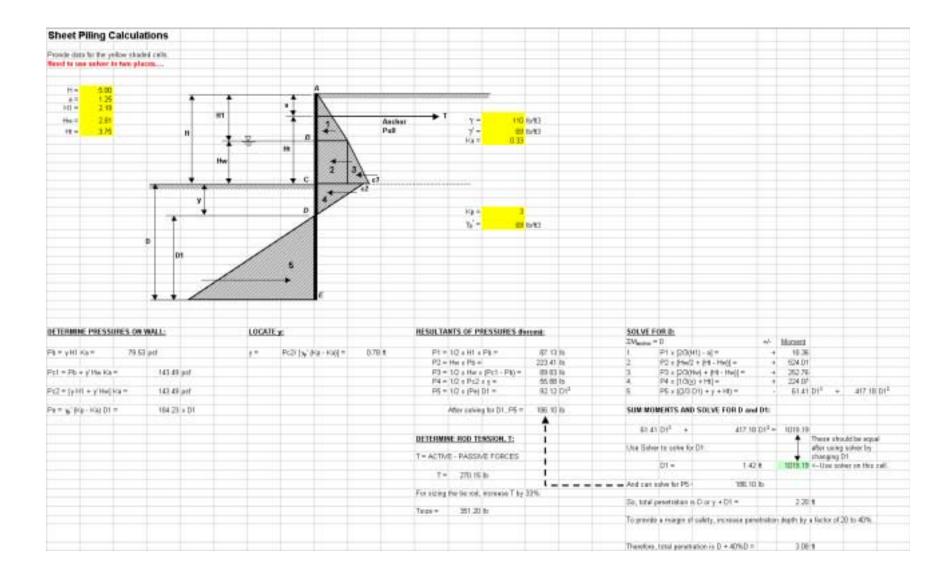
Appendix

A – Example: Steel Sheetpile Design Calculation SheetsB – Example: Riprap Revetment Design Calculation Sheets

C – Example: Steel Sheetpile Costing Sheets D – Example: Riprap Revetment Costing Sheets

Appendix A

Example: Steel Sheet Pile Design Calculation Sheets



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Appendix B

Example: Stone Revetment Design Calculation Sheets

Lake Michigan			
Increase/Decrease in Design Crest			
Calculation of Design Crest			
Depth at structure = Current Design Level			
Variable	Value	Units	NOTES
Height of Crest of Structure	500	n.	
Design Still Water Level, d,	2.91	n	Back Coculate to get d _a
Breaking Wave Height, H _s	219	n	Assume H _b = 0.78d _c
Slope (cot 0)	2.00		
Width of Structure	3:29		
Revetment Material (Quarrystone or Riprap?)	Riprap		#Hb > 5 t. then must use querystine, otherwise may use riprop. Table 3-3, EM 1110-2-1614.
Specific Gravity of Stone, S,	2.05		
Specific Weight of Water	62.4	04"	
Armor Stone Unit Weight, w,	165	tot ²	
Porosity for Armor Units (n)) 000	NO	Table 2.4 M 1110-3-1614 (assume quarystone random placed rough angular)
Stability Coefficient (Ko. Ker for riprap)	677		(Totale 2-3, EM 1110-3-1814) for much angular wil solph = 2
Stone Size and Layer Thickness:		\sim	-
Layer Thickness Coefficient (K ₄)	1974		(Toble 2-4, EM 1110-2-1014)
Armor Size Determination	86.73	tes	W _{III} for friprop
Average size of an individual riprap stone (Dia.)	0.94	n	Look up Value in Table 7-12, SPM
Quarrystone Layer thickness	NA	n	Eq. 3-23, EM 1110-3-1614 with number of Leyens, n=2
Riprap Layer thickness	1.07	n .	By swinton graded sprap Exckness is two times the stameter of the minimum W_{30} size
Number of quarrystones per area, N, (Area=1000 ft ²)	NA	stones/1000 fr ²	Eq 2-33.EM 1110-2-1614
Total Area:	-4.00	ugydsits	
Total Weight:	3.6	Torestm	
Toe Protection:	177	1000	Assuring moderate its severe scor potential
Toe Scour Depth (depth below the natural bottom), a	3.29	n	Assumed equal to the wave height, EM 1110-2-1614-1.5" Mitor Moderate to Severe Socur Potential
Median Weight of Toe Berm, W	89.73	905	Eq 2-15.EM 1110-2-1614
Crest Width or Width of top of Toe Berm, b	657	n	(Figure 2-4, EM 1116-2-1614)
Berm Height, 2 x r	3.74	п	(Figure 2-4, EM 1110-2-16)34)
Total Arealm:	340	sig yelseles	

Filters:			
Riprap underlayers			
Individual unit weight, W ₅₀	4.44	bs	W ₆₀ /20
Thickness	0.00	п	Must not be less than 0.75 tt or 0.23 m and must satisfy d _{ef} (cover) (d _{ef} (under) < 4. Eq. 7.123 w/ n=3.
Stone size, d _{SII}	0.30	n	Look up Value in Table 7-12, SPM
Total Area/m:	8-47	metrype	Includes area for toe protection also
Quarrystone underlayers			
First underlayer			
Individual unit weight	N/A	bs:	Witto
Thickness		-	n=2
Stone size	H 21		Lonk up Vale in Table 7-12, SPM
Total Area/m:	I G	Saydshir	<i>'</i>
Secondary underlayer	,		
Individual unit weight	N/A		V#200
Thickness	NA		n=2
Stone size			Look up Value in Table 7-12, SPM
Total Area/m:		egydslm	
Filter Blanket or Bedding Layer			Filter blanket, or bedding layer thickness should not be less than 1 ft or 0.3 meters, it is common practice to extend the bedding layer at least 1.5 meters beyond the toe of the ocver stone.
Cloth	8.87	sqyds/m	Includes area for toe protection also
Bedding Layer thickness	-100	n	Pg 7-242 SPM, Pea Gravel
Bedding Layer Area	647	sgyds/m	Includes area for toe protection also. Same area as underlayer.

Appendix C

Example: Steel Sheet Pile Costing Sheets

Sheet Piling Co	osts														
					Sheet Pi	ling									
Design Crest Height	Grade of Steel Selected		Allowable stress for selected steel	Required Section Modulus	Selected Section Designation	Section Modulus	lbs per sqft of wall	ight Ibs per lin ft of bar	Height of Pile (H), ft	Depth of Pile, ft (2 x H)	Area, sqftimete r	Unit Cost/sqft			
Existing + 3.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	20.16 in 7th of wall	PZ2T	30.2 in 7th of wall	27	40.5	00.8	16.00	T8.7	\$15.3			
Existing + 2.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	8.38 in Pit of wall	PZ22	18.1 in 7t of wall	22	40.3	7.00	14.00	68.9	\$15.3			
Existing + 1.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	2.95 in Pit of wall	P222	10.1 in 7th of well	22	40.3	6.00	12.00	59.1	\$15.3			
Existing	ASTM A572 Grade 50	50 ksi	32.1 ksi	0.02 in/ht of wall	PS31	2.0 in htt of wall	31	50.9	5.00	10.00	49.2	\$15.3			
Existing - 1.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	0.14 in/lit of wall	PS31	2.0 in htt of wall	31	50.9	4.00	8.00	39.4	\$15.3			
Existing - 2.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	0.03 in/lit of wall	PS31	2.0 in htt of wall	31	50.9	3.00	6.00	29.5	\$15.3			
Existing - 3.0 ft	ASTM A572 Grade 50	50 ksi	32.1 ksi	0.01 in7th of wall	PS31	2.0 in to of wall	31	50.9	2.00	4.00	19.7	\$15.3			
			Sh	eetpiling Continue	d		Backfill Toe Protectio					e Protection	1		
	Design Crest Height	Cost for Sheetpile	Cost for Steel	Wales and rods	Anchor (Deadman)	Cost	Volume	Unit Cost	Cost	Excavation	Pea Stone	Filter Cloth	Cover Layer	Total Cost	
		Simeter	(by toes) S/meter	Streeter	\$/meter	\$/meter	cuyd/m	\$ per cuyd/m	\$/meter	\$/meter	\$/meter	\$imeter	\$/meter	Simeter	
	Existing + 3.0 ft	\$1,204.0	\$659	\$500	\$108	\$1,012.38	7.8	\$4.30	\$33	\$184	\$98	\$12	\$500	\$2,728	
	Existing + 20 ft	\$1,054.2	\$470	\$500	\$108	\$1,662	6.0	\$4.30	\$26	\$143	\$86	\$11	\$261	\$2,187	
	Existing + 1.0 ft	\$903.6	\$402	\$500	\$108	\$1,511	4.4	\$4.30	\$19	\$107	\$73	\$9	\$191	\$1,910	
	Existing	\$753.0	\$429	\$500	\$108	\$1,361	3.0	\$4.30	\$13	\$77	\$61	\$8	\$124	\$1,644	
	Existing - 1.0 ft	9602.4	\$343	\$500	\$108	\$1,210	1.9	\$4.30	98	\$51	\$49	98	\$68	\$1,392	
	Existing - 2.0 ft	\$451.0	\$257	\$500	\$100	\$1,059	1.1	\$4.30	\$5	\$31	\$3.7	\$5	\$30	\$1,174	
	Existing - 3.0 ft	\$301.2	\$171	\$500	\$108	\$909	0.5	\$4.30	\$2	\$15	\$24	\$3	\$17	\$971	

Appendix D

Example: Stone Revetment Costing Sheets

Stone Revetment	Existing Design Level	
Design Parameter	Units	Note
ds	2.81 ft	Design water level
H _b	2.19 ft	Breaking wave height (Hb) = 0.78 * design water level
Crest elevation, H	5 ft	Crest Elevation = 1.0 Hb above design water level
erect cioralieri, i	.	Cross Elevation = 1.0 rb above adolg. Materiore.
Layer 1 - Cover Layer		
Slope (cot ϕ)	2.0	
Revement Material	Riprap	Quarrystone if H _b > 5.0 ft wave height
Armor Size	88.73 lbs	Quarrystone ii 116 > 5.0 it wave height
Armor Size Average Size	0.94 ft	
Layer Thickness	1.87 ft	
Area of Layer	4.1 sqyd/m	
Weight	3.57 tons/m	Considering Porosity of 37%
weight	0.07 (010/11	Considering Foresity of 57 /0
Layer 2 (also under toe protection)	- Underlaver	
Individual Unit Weight	4.4 lbs	
Average Size	0.30 ft	
Layer Thickness	0.9 ft	
Area of Layer	6.5 sqyd/m	
Weight	2.72 tons/m	Considering Porosity of 37%
Layer 3 (also under toe protection)	- Bedding Laver	
Material	Pea Stone	
Layer Thickness	1.0 ft	
Area of Layer	6.5 sqyd/m	
Volume	2.2 cuyd/m	
- Filter Cloth		
Area of Layer	8.9 sqyd/m	
Toe Protection		
Excavation for toe protection	13.52 cuyd/m	
Armor Size	88.73 lbs	
Berm Height, a	3.74 ft	1.5 H _b or 2 x r
Crest Width, b	6.57 ft	2 x a
Area of Layer	2.40 sqyd/m	
Weight	4.19 tons/m	Considering Porosity of 37%
-	a annual fan all daalmus	
Site Preparation Costs - Assume	e equai for all designs	

Materials Costs - Typical Design

Item Layer 1 (Cover Lag	Item Layer 1 (Cover Layer)		Units tons/m	Unit Cost (\$) \$30	Total Cost (\$) \$106	Notes ~ 100 lb stones	Source pg 60 Means (022 712 0350) material, labor and equip (022 712 0100) In practice, because of resulting layer thicknesses, the cover layer and
Layer 2 (Underlayer Layer 3 (Bedding L	,	2.7	tons/m	\$30	\$81		underlayer would be combined. Therefore, used same unit cost as cover
3	Pea Gravel	2.2	cuyd/m	\$26	\$55		pg 97 Means (027 054 0400)
	Filter Cloth	8.9	sqyd/m	\$2	\$14		pg 97 Means (027 054 0110)
Toe Excavation		13.5	cuyd/m	\$6	\$77	(1-4' deep)	pg 51 Means (022 254 0050)
Toe Protection		4.2	tons/m	\$30	\$124	~ 100 lb stones	pg 60 Means (022 712 0350)
Total Cost per lin	eal meter				\$456		